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Addressing India's energy security and options for decreasing energy dependency

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ABSTRACT

Energy plays the most vital role in the economic growth and security of any nation. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmental friendly. Acute energy scarcity in India in recent years is hampering its industrial growth and economic progress. India is strongly dependent on the fossil fuels for its energy requirements which are also contributing significantly to greenhouse gases emissions. It is proposed that the introduction of renewable energy sources portfolio to the future energy mix and diversification of fuel sources will (i) enhances energy security and mitigates CO_2 emission, and (ii) improves the quality of life. If India failed to protect its environment, not only its economic growth would be impeded but also would pose serious health hazards.

Contents

1. Introduction

Energy plays the most vital role in the economic growth and security of any nation. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally friendly. In recent decades, overwhelmingly increase of development activities trigger the increasing demand for the energy [1–3]. Globally fossil fuel contribution is the major share of the energy mix of several countries, including India which is also one of the main sources of CO_2 emissions. Energy, climate change, environmental, and health issues are intertwined. Furthermore, unhealthy workforce seriously affects the country's economic growth and productivity. Therefore for the sustainable future economic progress and industrial growth, these issues need to be addressed collectively.

India is facing the critical challenge of meeting a rapidly increasing demand for energy. India ranks sixth in the world in terms of total energy consumption. To meet the growth aspirations of over a billion people, it needs to accelerate the development of the sector. The current levels of per capita energy consumption in India are extremely low as compared to the rest of the world. In 2008–2009, per capita energy consumption was about 530 kgoe (kilogram oil equivalent), compared to the global standard of nearly 1800 kgoe [4].

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Uninterrupted energy supply is a vital issue for all countries today, even more so far India at its current stage of development. Earlier, various options available to address India's energy vulnerability and external threat to the supply of energy fuels were analyzed by Bramha Chellaney [5]. Issues related to oil demand, import dependency, and security have been presented by Tanvi Madan [6]. Recently, Parikh has discussed issues such as low carbon growth, new energy resources and various options pertaining to future energy security [7]. It is projected that the solar energy can meet the energy requirement of India and power cost competitive to coal power by 2020.

Lack of energy resources could jeopardize not only India's economic progress but also security and strategic interest. Adequate quantities of economically priced clean, sustainable and green fuels need to be made available to the Indian consumers. In a new paradigm, sustainable economic growth and industrial development without endangering the climate are envisaged. In the present review article, energy security, use of alternative fuels, diversification of energy mix, and the feasibility of interchangeability of mix of energy sources of India are discussed.

2. Present scenario of energy mix

World Energy Outlook projected that the world primary energy demand is increasing by 1.5% per year between 2007 and 2030, from just over 12,000 to 16,800 Mtoe (million tonnes of oil equivalent) with an overall rise of 40% [8]. Fig. 1 shows the world energy mix in 2008 [9] and 2030 [10] in the reference scenario based on current policies. The total energy mix size is projected to increase from 11294.9 Mtoe in 2008 to 17014 Mtoe in 2030 in the reference scenario with current policies as estimated by the International Energy Agency (IEA) [10]. Fossil fuels such as coal, oil

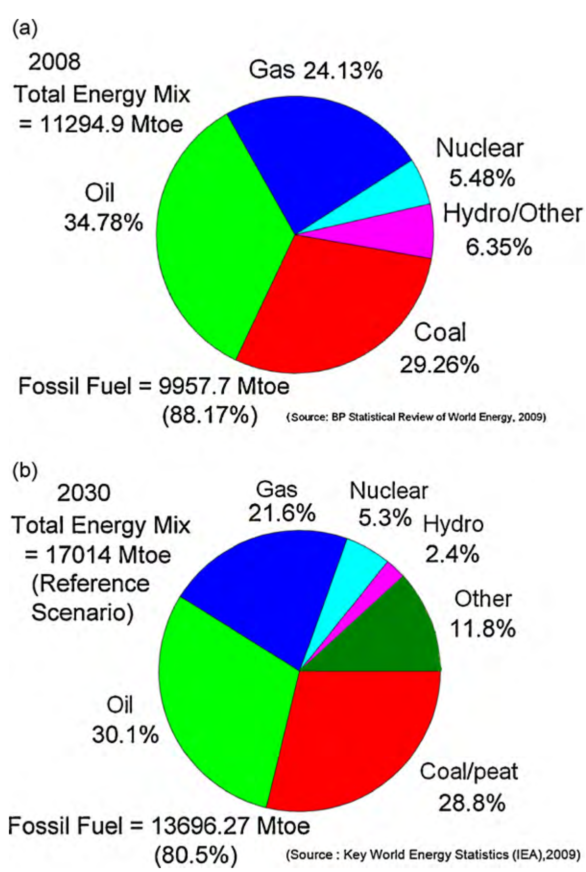


Fig. 1. (a) World energy mix in 2008 and (b) 2030 in the reference scenario based on the current policies.

Table 1
Energy mix of some industrialized and developing countries in 2008.

Country	Energy mix				Ref.
	Fossil (%)	Nuclear (%)	Renewables (%)	Other (%)	
Luxembourg	92	0	2	6	[11,12]
United States	86	8	6	0	[11,12]
Australia	97	0	3	0	[11,12]
Canada	67	7	25	0	[11,12]
Finland	59	16	23	2	[11,12]
Belgium	75	22	2	1	[11,12]
Ireland	97	0	2	1	[11,12]
Netherlands	94	1	3	2	[11,12]
Germany	84	12	4	0	[11,12]
Denmark	85	0	14	1	[11,12]
Japan	83	12	5	0	[11,12]
Norway	37	0	60	0	[11,12]
Austria	77	0	21	2	[11,12]
United Kingdom	89	9	2	0	[11,12]
Italy	90	0	7	3	[11,12]
New Zealand	71	0	29	0	[11,12]
Iceland	27	0	73	0	[11,12]
France	52	40	6	2	[11,12]
Bulgaria	71	22	5	2	[11,12]
Portugal	83	0	15	2	[11,12]
Sweden	37	37	26	0	[11,12]
Switzerland	63	24	13	0	[11,12]
Brazil	62.45	1.36		36.08 (hydro)	[9]
China	92.6	0.77		6.61 (hydro)	[9]
India	92.82	0.80		6.06 (hydro)	[9]
Indonesia	97.80			2.16 (hydro)	[9]
South Korea	85.32	14.22		0.37 (hydro)	[9]
World Mean	87	6	6	1%	

and natural gas remain the dominant sources of primary energy worldwide, accounting for the 50% overall increase in energy use between 2008 and 2030. In absolute terms, coal sees the biggest increase in demand over the projection period, followed by gas and oil. Although oil remains the single largest fuel in the primary fuel mix in 2030, its share will drops from 34% now to 30%. The energy mix of some industrialized and developing countries are listed in Table 1 [9,11,12]. Four developed countries namely Iceland, Norway, Sweden, and Finland have renewables contribution of 73, 60, 26, and 23% in the total energy mix, respectively. Whereas, France, Sweden, Switzerland, and Belgium have 40, 37, 24, and 22% of nuclear in their energy mix, respectively. Interestingly, the energy mix of Iceland has the highest fraction of the renewables (72.6%) of any country and that of only 27.4% of fossil fuel contribution. On the other extreme, the performance of United States of America (USA) on energy mix portfolio is not encouraging as it is strongly dependent on the fossil fuel (86%) as regard to 8 and 6% of nuclear and renewable energies, respectively. Also noteworthy are Australia (97%), Ireland (97%) and Indonesia (97.8), their economies almost entirely reliant on fossil fuels. These results demonstrate that the interchangeability of mix of energy sources model is practically feasible.

The main driver of demand for the fossil fuels is the inexorable growth in the energy needs for the power generation. World net electricity generation increases by an average of 2.4% per year from 2006 to 2030 in the International Energy Outlook (IEO) 2009 reference case, a net increase by 77% [13]. Non-OECD countries are expected to contribute nearly 90% of the total world energy demand growth [13]. Population growth and mass industrialization in emerging economies are two main factors driving these figures [14]. Fossil fuels are expected to provide the bulk of primary energy in 2030 mainly due to the continued reliance on the existing coal-fired plants. Coal continues to provide a secure energy source for many consuming countries although there is a major concern about the greenhouse gas (GHG) emissions. Fig. 2 shows the contribution to the anthropogenic GHG emissions due to

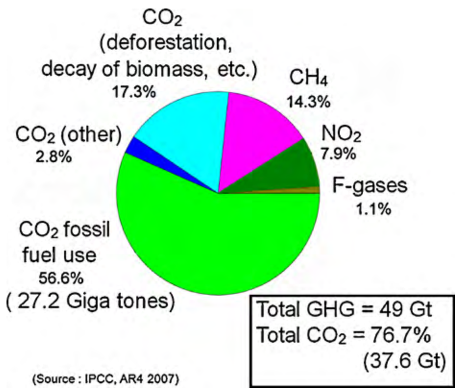


Fig. 2. Contribution to the anthropogenic Green House gas emissions.

the various human activities [15,16]. Use of fossil fuels contributes about 56.6% of all GHG emissions. Global emissions of carbon dioxide from the three fossil fuels in 2008 are shown in Table 2 [17]. Although China's total emission (21.67%) has taken over the US (20.22%), its annual per capita emissions of 4.88 tonnes CO_2 is much lower than those of USA, Canada, and Australia at 19.96, 18.82, and 17.72 tonnes, respectively. As seen from the Table, India's annual per capita CO_2 emission is merely 1.17 tonnes which is much below that of the World average at 4.51 tonnes. Emissions from the three major developing nations of Brazil, China and India are accounted for 27.57% of the world total emission in 2008. While other countries designated here as the rest of world are accounted for 22.09% of the emissions. Per capita emission from this part of the world is also low at 2.42 tonnes CO_2 per person.

Another concern regarding the primary energy sources which has attracted attention of several developing and developed economies is the energy security with uninterrupted supply of energy fuels. This issue needs to be addressed as these fuel sources are concentrated in a few countries. Unfortunately, primary fuel materials required to produce energy are not evenly distributed throughout the world. In fact, some countries in recent days are hopelessly marginalized by the global price volatility, increasingly competitive world demand, and associated geopolitical hazards. Faced with serious concern to the energy security, competition for acquiring the overseas energy resources by developing and developed economies is significantly intensified in recent years.

Global oil concentration is shown in Fig. 3 [18] and Table 3 [9]. Around 60% of the world's proved oil reserves in 2008 are located in Middle East countries. While 57% of the world's proved gas reserves in 2008 are found in just three countries Russia, Iran and Qatar as displayed in Fig. 4 and Table 3. While, world's proved coal reserves are more evenly located around the globe except Middle East and South American Countries as listed in Table 3. Middle East

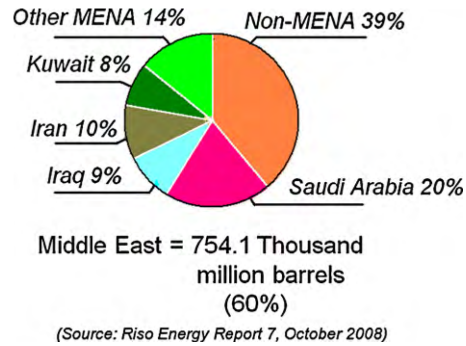


Fig. 3. Global oil concentration in 2008.

Table 3
Proved global oil, natural gas and coal (including anthracite and bituminous coal) at the end of 2008.

Region	Oil (thousand of million barrels)	Natural gas (trillion cubic meter)	Coal (thousand million tonnes)
Asia Pacific	42.0	15.39	155.8
North America	70.9	8.87	246.1
South and Central America	123.2	7.31	15.0
Africa	125.6	14.65	320
Europe and Eurasia	142.2	62.89	272.2
Middle East	754.1	75.91	1.4

and African countries are rich in energy resources which are sufficient to meet the current levels of world energy demand. As a consequence, many developed and developing economies are investing in Latin America, Africa and Asian countries to secure energy resources. Indeed, recent political interest of several countries in Africa illustrates their energy security concerns. Political instability and disruption of production and distribution chains due to accidents or natural events in key energy producing regions are further adding anxieties to consuming countries. Individual consuming countries continue to face specific energy security issues related to cost, geography and political relationships with producers. Diversifying oil and gas supply sources may be one strategic approach to enhancing energy security for many counties, but does not address the climate change issue.

3. Energy mix of India

Fig. 5 displays the India's energy mix in 2008 [9]. Coal contributes about 54% of the commercial energy. Although India is a major producer of coal, it produces only limited quantities of coking coal. As a result, about 59.0 million tonnes (~12% of the total consumption) of coking and high-grade thermal coal was imported from Indonesia, Australia and South Africa in 2007–2008.

Table 2
Global emissions of carbon dioxide from the three fossil fuels in 2008.

Country/region	Oil (%)	Natural gas (%)	Coal (%)	Total 2008 (%)	% of World	CO_2 emissions per capita tonnes/p.c.
World	40.0	19.3	40.7	100	100	4.51
Canada	49.9	30.5	19.6	100	2.08	18.82
USA	44.6	21.0	34.4	100	20.22	19.96
EU (25)	51.2	22.3	26.5	100	13.99	8.55
East Eur.+ CIS	25.3	46.5	28.2	100	8.39	8.29
Australia	35.6	12.3	52.1	100	1.22	17.72
Brazil	75.9	11.4	12.7	100	1.41	2.20
China	17.6	2.4	80.0	100	21.67	4.88
France	68.7	20.6	10.7	100	1.37	6.46
India	30.6	5.9	63.5	100	4.49	1.17
Japan	50.9	13.4	35.7	100	4.44	10.49
Rest of world	53.0	25.7	21.3	100	22.09	2.42

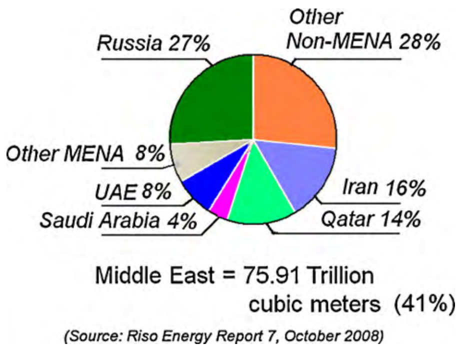


Fig. 4. World's proved gas reserves in 2008.

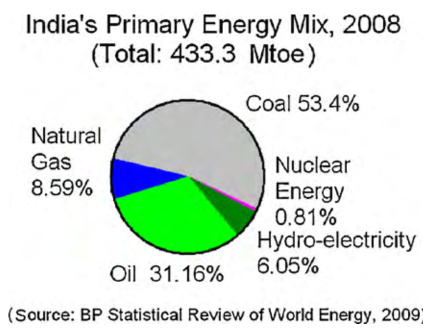


Fig. 5. India's energy mix in 2008.

As well, oil and gas continue to play a pre-eminent role in meeting the energy requirements of the country. About 45% of the total energy needs would be met by the oil and gas sector [19]. India produces oil about 880, 500 bbl/day while imports about 2.159 million bbl/day, whereas natural gas production is about 31.7 billion cubic meter and imports 10 billion cubic meter [20]. Oil is mainly imported from Nigeria, Saudi Arabia, Kuwait, Iran and Iraq. In recent years, the natural gas consumption is growing fast. Further, its demand is expected to increase to 400 million standard cubic meters (MSCN) per day in 2024–2025 as against its production of 100 MSCN per day. At present, India imports natural gas from Algeria, Egypt, Nigeria, Oman, Qatar, United Arab Emirates, Australia, and Malaysia.

India's energy vulnerability is greater as in recent years it becomes an oil and natural gas importers and likely to enhance in the future. Although the current level of per capita energy consumption in India is extremely low as compared to the rest of the world, its economy is growing at a rate of 7–10% of gross domestic product (GDP) with a rapidly increasing demand for energy. Figs. 6 and 7 show the projected energy mix size increase and primary fuels wise energy contribution, respectively [21].

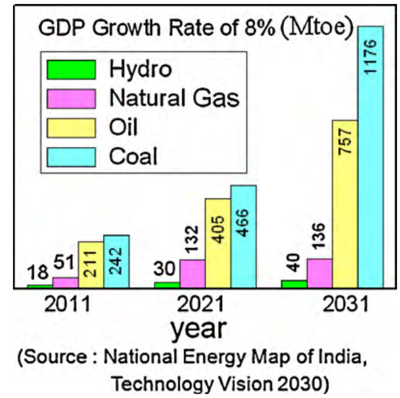


Fig. 7. Projected primary fuels wise contribution to energy mix of India.

With a moderate 8% growth of GDP, the energy mix size is projected to grow from 433.3 Mtoe in 2008 to 2123 Mtoe in 2031in the reference scenario.

Its concern over the energy security arises from increasingly dependence on the overseas supply of coal, oil and natural petroleum products. Overall, India's energy future appears dependent on the high-volume imports of fossil fuel materials.

3.1. Coal

Coal has been the fastest growing fuel in the world and its use is expected to grow faster than any other fuel far into the future. In 2007–2008, 266.71 million tonnes of coal and 20.27 million tonnes of lignite were used for commercial energy requirements in India [22]. Fig. 8 shows the coal reserves in India (2008–2009). As on April 2009, India has estimated coal reserves of 267.2 billion tonnes (Proved Reserves 105.8 Billion tonnes, Indicated 161.4 Billion tonnes). While estimated lignite resources are 38.93 billion tonnes (Proved: 4.82 billion tonnes). Extractable reserves of 55 billion tonnes may lost for 50 years with the projected level of production. The total production of coal in 2008–2009 was about 403.7 million tonnes. While about 59.0 million tonnes of coal was imported from Indonesia, Australia and South Africa. India has imported around 51 million tonnes of coal in the year ended March 2009. The country is expected to import 100 million tonnes of coal by 2013. In 2030, the projected import of coal is about three times the 2007 level (about 49 million tonnes), spurred by rising imports of both coking and steam coal. The planned large electricity plants for coastal areas are to be fueled by the imported steam coal [23]. At present, India seems to be comfortable with the reserves of this resource. However for the production of clean energy from the coal without endangering the climate, its dependency on the imported high-grade thermal coal is likely to be increased from present 10 to

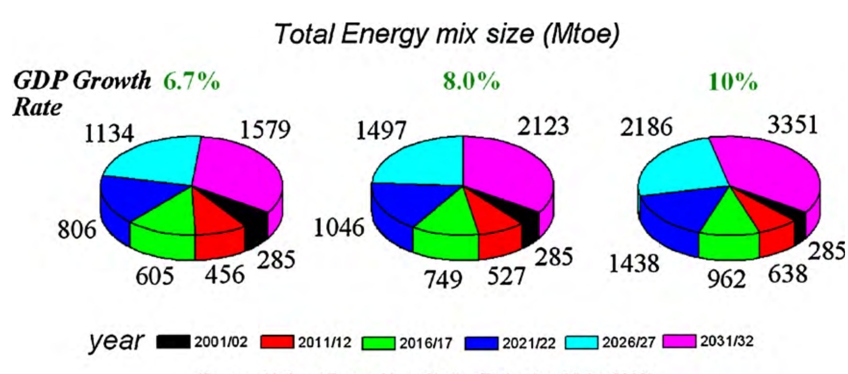


Fig. 6. Projected total energy mix size of India.

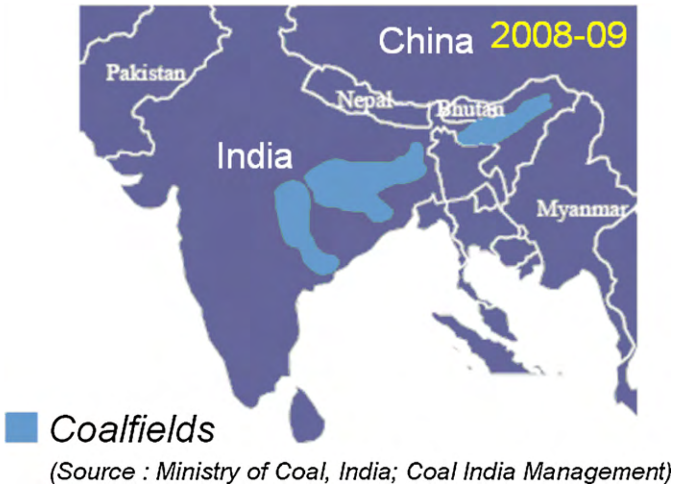


Fig. 8. Coal reserves in India (2008–2009).

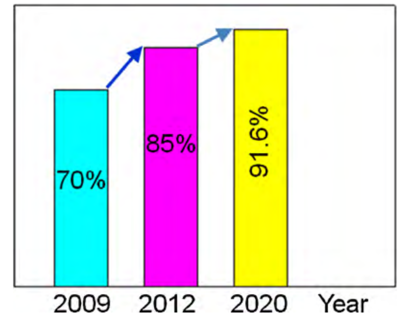


Fig. 9. India's current and projected future oil import dependency.

70% by 2030. Recently, India has also invested in two virgin blocks in Mozambique.

3.2. Oil

While India has significant reserves of coal, it is relatively poor in oil and gas resources. Its oil reserves amount to 5.9 billion barrels over 0.5% of global reserves with total proven, probable, and possible reserves of close to 11 billion barrels. The majority of India's oil reserves are located in fields offshore Mumbai and onshore in Assam. However, the domestic production is quite not enough to meet the growing requirements. The country's annual demand for the oil is expected to increase at an average rate of 2.9% over the next quarter century, while domestic production is expected to remain constant. Fig. 9 shows the India's current and projected future oil import dependency. Due to the stagnating domestic crude production, approximately 70% of its oil has been imported in 2009, mostly from the Middle East countries and its dependency is growing rapidly. World Energy Outlook, IEA projects that India's dependence on the oil imports will grow to 91.6% by the year 2020 [8]. The Energy Information Administration (EIA) expects India to become the fourth largest net importer of the oil in the world by 2025, behind the United States, China, and Japan [24].

Concerned about its growing reliance on oil from the Persian Gulf (65% of its energy is imported from this region), India is looking regions beyond the Gulf for seeking oil. Investment in overseas oilfields Indian companies is projected to reach $3 billion within a few years. In Africa, especially in Sudan, India has invested $750 million in oil, and also from Nigeria, it has reached an agreement to purchase about 44 million barrels of crude oil per year on a long-term basis. Additionally, India is also invested in Syrian Company for the exploration, development and production of petroleum. Sakhalin, in Russia, and Vietnam and Myanmar in Southeast Asia are also potential suppliers to the Indian market. But the most attractive oil domain outside the Persian Gulf is the Caspian Basin where India is trying to befriend the region's leaders and, if possible, gain a foothold. India is also pursuing relations with Kazakhstan, Azerbaijan and Iran.

3.3. Natural gas

Natural gas is emerging as the preferred fuel of the future in view of it being an environmental friendly, economically attractive fuel and also a desirable feedstock. Increased focus needs to be given to this potential sector. Natural gas has emerged as one of the most preferred fuel due to its environmentally benign nature, greater efficiency and cost effectiveness. India had 38 Tcf (trillion cubic feet) of proven natural gas reserves as of January 2009 [25]. The Energy Information Administration (EIA), DOE, US Govt. estimates that India produced approximately 1.1 Tcf of natural gas in 2007 [25]. While, it has consumed roughly 1.5 Tcf of natural gas in 2007, approximately 100 Bcf (billion cubic feet) more than in 2006. The recent success of the discovery of the Godavari basin in the Andhra Pradesh region has not only improved the energy security of the country by boosting possible gas production by 50%, but also raised the prospects of Indian sedimentary basins in the international arena.

Natural gas demand is expected to grow considerably, largely driven by the demand in the power sector. Fig. 10 displays the current and projected natural gas import [20,26]. Although India's natural gas production has consistently increased, the demand has already exceeded the supply and the country has been a net importer of the natural gas since 2004. Despite major new natural gas discoveries in recent years, India is considering large-scale

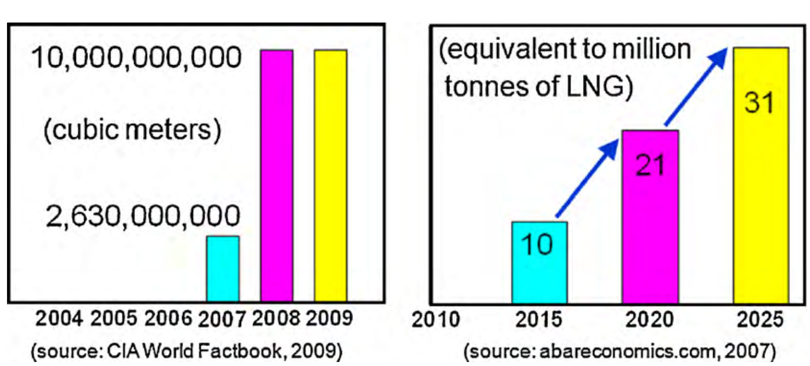


Fig. 10. Current and projected natural gas import.

imports via pipelines and LNG terminals to help meet growing demand. India's net imports reached an estimated 353 Bcf in 2007. India imports natural gas via liquefied natural gas (LNG). India's LNG imports in 2006 came from Algeria, Egypt, Nigeria, Oman, Qatar, United Arab Emirates, Australia, and Malaysia. Natural gas consumption in India is projected to grow to 82 Bcf in 2025.

In summary, fossil fuels play an invaluable role in supplying the heat, light and mobility required by a growing population and projected to increase their demand in future. While accomplishing the energy need using primary energy sources, it is imperative to address the challenges of energy security with uninterrupted supply of fuels, climate change and health hazards due to environmental pollution. The problem lies in the use of fossil fuels and biomass combustion, which are notoriously inefficient at producing usable energy. In order to realize the goal of energy security and climate change and sustainable industrial and economic developments, use of 'decarbonize' future energy mix such as wind, solar and biofuels which emit no CO_2 offers the solution.

4. Alternative energy mix

4.1. Renewable energy mix

Diversification of fuel sources is imperative to address the energy security, climate change, and sustainable development issues. Furthermore, too much reliance on the non-renewable sources to generate power is also unviable in the long run. Thus, it is essential to address the energy crisis through the extensive utilization of abundant renewable energy resources, such as biomass energy, solar energy, wind energy and geothermal energy. Many countries have set ambitious targets for the renewable energy. Presently, renewable energy worldwide is still dominated by the "old" renewable such as hydropower and traditional biomass that supply 6 and 9% of global primary energy demand, respectively. Only around 2% of the world's primary energy is currently provided by "new" renewable sources such as wind, photovoltaics and mini- and micro-hydro. Solar radiation is natural, free, and an abundantly available source of energy; there is no investment in receiving the sun light and no nation has the ability to solely control it. Both poor and rich nations equally receive the solar radiation emitted by the sun.

Industrial growth and economic progress of India is hampering due to the acute energy scarcity. With the forecasts of faster growth of the economy in the near future, the demand for the energy will surely increase from all the sectors. India's major energy comes from coal, which has the highest CO_2 emission coefficient. In order to address issues pertaining to energy security and climate change and sustainable development, India needs to adopt clean and sustainable energy mix. Nuclear power generation, new and renewable energy, and energy conservation seem to be important on a mid-to long-term basis. In this context, solar energy offers enormous potential for a tropical country like India. Fig. 11 shows the solar insolation map of India [27]. India receives solar energy equivalent to more than 5000 trillion kWh per year, which is far more than its total annual energy consumption. The intensity and duration of sunlight available on India's landmass is relatively greater than in many other regions of the world. In fact, only 1% of India's land area can meet its entire electricity requirements up to 2030 [28]. Recently, the Federal Government has unveiled the roadmap to expand the solar energy which is displayed in Fig. 12 [29]. Solar mission draft aims to develop 20 GW grid quality solar power by 2022. This is the most aggressive program in the world. It is interesting to note whether ambitious development policies can be achieved without any overseas savoir-faire. But it is sure that the large amount of investment will definitely give strong impetus to the development of solar industry in the country.

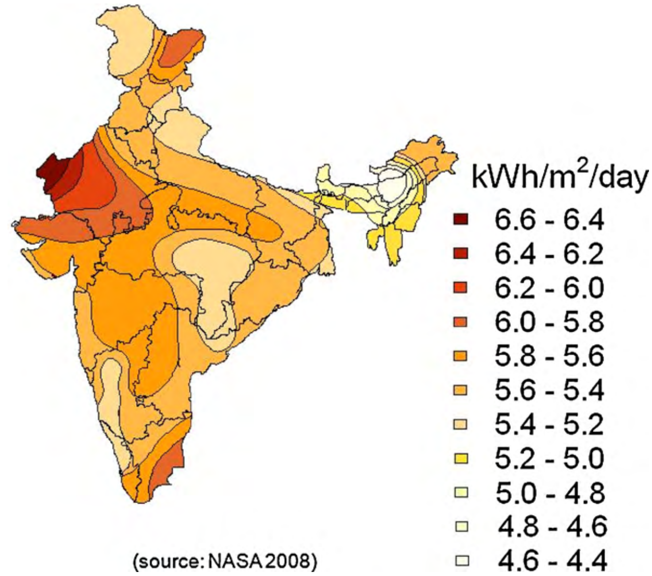


Fig. 11. Solar insolation map of India.

Furthermore, India has a great untapped potential of wind energy. Fig. 13 shows the standard wind map of India. It is estimated that the country's total wind resource amounts to 45–48 GW [30]. Potential of Renewable Power of various sources obtained from different studies are summarized in Table 4 [7,31,32].

4.2. Estimation of CO_2 emission

For the sustainable development without endangering the climate, the future energy mix is envisaged to be (i) nuclear fuel intensive, (ii) natural gas intensive, and (iii) renewable sources intensive. India's total energy mix size in 2031 is projected to be 2123 Mtoe in the reference scenario, including 2069 Mtoe (97% of the total size) contribution from fossil fuels (Figs. 6 and 7). In the present review, CO_2 emissions due to combustion of these fossil fuels in the energy mix are analyzed using simple technique [33]. Although the obtained results do not account the absolute emission figures as it depends on the fuel quality used and preparation, but the

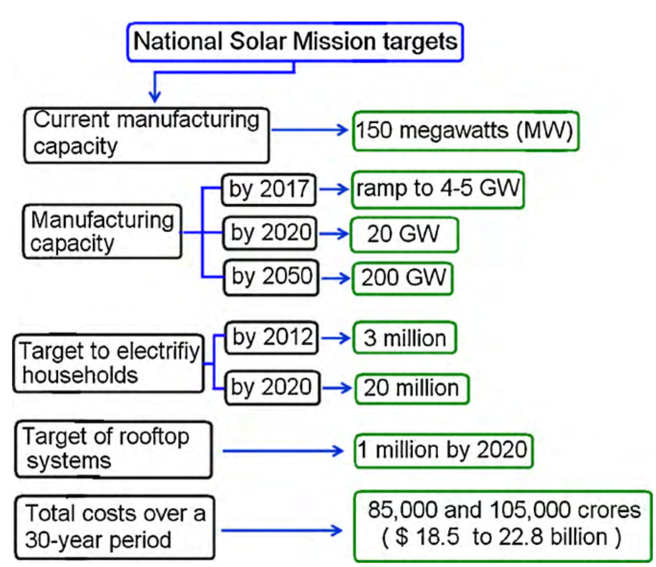


Fig. 12. National Solar Mission unveiled by the Federal Government in 2009.

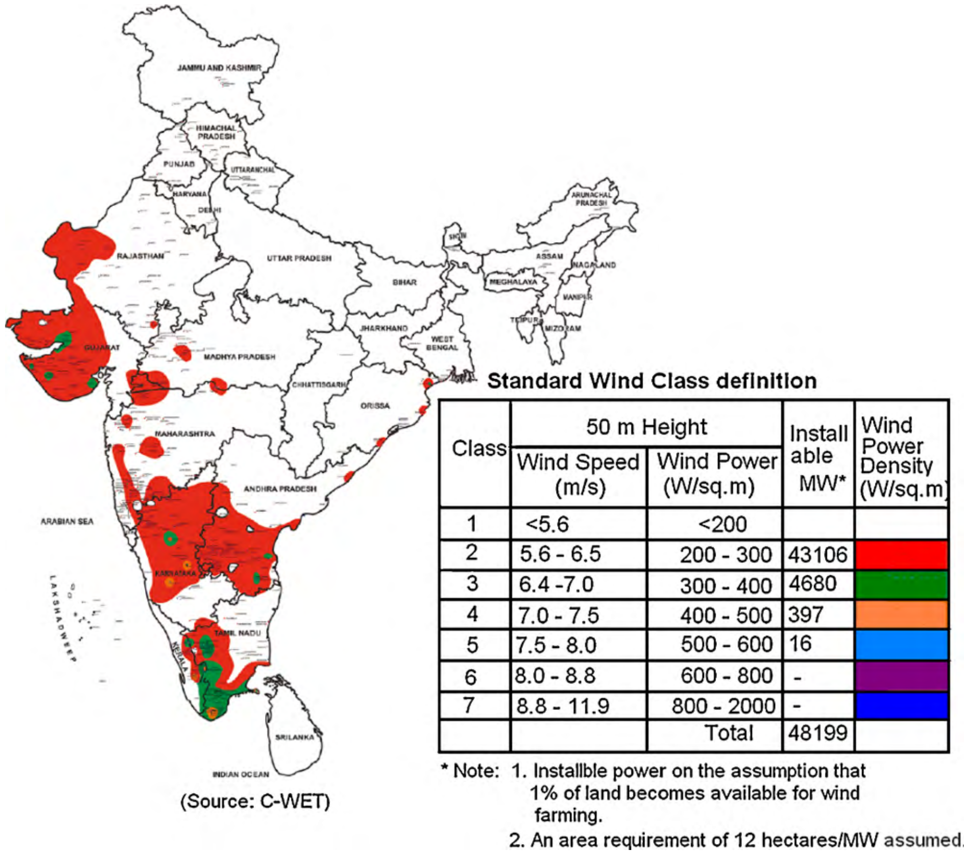


Fig. 13. Potential of wind energy map of India.

resulting trends give confident relative results. The CO_2 emission factors for the combustion of fossil fuels are [33]:

Oil $\rightarrow$ 260 gCO_2/kWh

Naturalgas $\rightarrow$ 195 gCO_2/kWh

Coal $\rightarrow$ 330 gCO_2/kWh.

Since 1 tonne of oil equivalent (toe) is equal to 11,600 kWh, the CO_2 emissions per combustion of toe are:

Oil $\rightarrow$ 3.01 tCO_2/toe

Naturalgas $\rightarrow$ 2.262 tCO_2/toe

Coal $\rightarrow$ 3.828 tCO_2/toe.

In the modified energy mix, the fossil fuel contribution of 97% (or 2069 Mtoe) in the reference scenario was reduced to 90, 80, and 70%. The CO_2 emission estimated using the simple technique as discussed above is illustrated in Table 5 and displayed in Fig. 14. The total 7.087 Gt CO_2 emission from the fossil fuels in the reference scenario will significantly be reduced to 5.10 Gt CO_2 by decreasing the fossil fuels contribution to 70% of the total energy mix in the modified energy mix in 2031. In 2031, fivefold increase of CO_2 emission from the fossil fuels of energy mix in the reference scenario as compared to 1.376 Gt CO_2 emission from the 403.6 Mtoe of fossil fuels contribution to 433.3 Mtoe of total energy mix size in 2008, is estimated. By altering the energy mix, the CO_2 emission could be substantially mitigated. It may be mentioned here that any reduction of the contribution of fossil fuels to the total energy mix is accompanied by the increase of renewable and nuclear energy shares. Since the fossil fuel contribution variation of current energy mix (2008) from 97 (in Australia) to 28% (in Iceland) is practically feasible as displayed in Table 1, the variation of 97–70% fossil fuel contribution to the future energy mix of India is the most appropriate and hence

Table 4
Potential of renewable power in India obtained from various studies.

Sources	Cumulative installed capacity as on September 2007 (MW)	Estimated mid-term 2032 Ref. [31] (MW)	Potential estimated as in Ref. [7]	Potential estimated as in Ref. [32] (MW)
Wind power	7660	45,000	10 Mtoe/year[a]	45,195
Bio-power (Agro residues and plantations)	560	61,000	140.7 Mtoe/year	16,881
Biofuels			30 Mtoe/year	
Co-generation Baggasse	692	5000		5000
Hydropower			150,000 MW[b]	
Small hydro (up to 25 MW)	2014	15,000	5 Mtoe/year	15,000
Waste to energy	55	7000		2700
Solar photovoltaic	2.74	50,000	1200 Mtoe/year	2600×10^3 (PV + CSP)
Thermal			1200 Mtoe/year	
Total	10983.74	183,000		

[a] Onshore potential of 65,000 MWe (Megawatt equivalent) at 20% load factor.
[b] Total potential assessed is 84,000 MW at 60% load factor or 150,000 MW at lower load factor.

Table 5
Estimated CO_2 emission in modified energy mix in 2031.

Fuel	Fossil fuels in reference scenario energy mix in 2031		Modified energy mix					
	97% Mtoe	Gt CO_2	90% Mtoe	Gt CO_2	80% Mtoe	Gt CO_2	70% Mtoe	Gt CO_2
Oil	757	2.28	702.37	2.11	624.32	1.88	546.28	1.64
Coal	1176	4.5	1091.13	4.176	969.89	3.71	848.65	3.25
Natural Gas	136	0.307	126	0.28	112.164 0.25	98	0.22	
Total	2069	7.087	1919.5	6.57	1706	5.84	1493	5.10

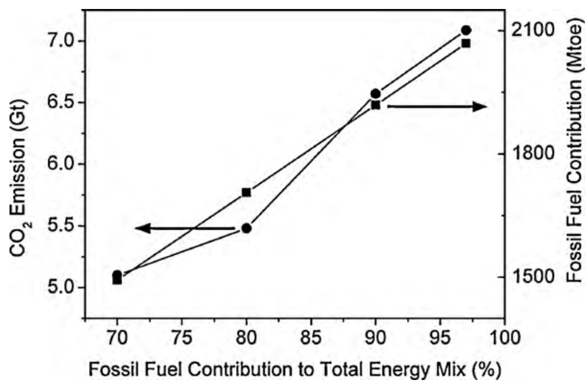


Fig. 14. Estimated CO_2 emission due to fossil fuels use in energy mix reference scenario in 2031.

selected here for the estimation of CO_2 emission. Furthermore, the CO_2 emission could be manipulated by altering the contribution of different constituents of fossil fuels. Aggressive implementation of renewables and clean fuels to the energy mix not only reduce the overseas dependency for energy fuels but also help to (i) enhance the energy security, (ii) mitigate CO_2 emission, (iii) reduce environmental pollution, and (iv) reduce health hazards.

5. Conclusions

Future of human prosperity depends on how successful two central challenges, namely (i) securing the supply of reliable and affordable energy, and (ii) adopting a low carbon, efficient and environmentally benign system of energy supply, are addressed. To address these concerns, it is essential to shift to energy sources that can substantially reduce CO_2 emissions compared with fossil fuels rather than concentrating energy-saving efforts on the existing energy portfolio. In this regard, clean energies like renewable would be an important alternative.

Issues such as energy security, use of alternative fuels, interchangeability of technology are vital to ensure that the mix of energy sources used in the economy is optimal and sustainable and that adequate quantities of economically priced clean and green fuels are made available to the Indian consumers. In the modified energy mix (renewable intensive), the total 7.087 Gt CO_2 emission from fossil fuels can be reduced to 5.10 Gt CO_2 in 2031 in the reference scenario by reducing the fossil fuels contribution to 70%. As mentioned in Ref. [7], solar energy share (2400 Mtoe) alone is sufficient to meet the entire energy requirement (2123 Mtoe in 2031 in the reference scenario) of India. Most of the technology needed to shift from fossil fuel to clean and renewable energy already exists. Introduction of renewable portfolio in the future energy mix of India (i) eliminates the combustion as a way to generate power for normal electricity use as well as for vehicles, (ii) assure the energy security, and (iii) enhance the quality of life. If it allows carbon- and air pollution-emitting energy sources to play a substantial role in the future energy mix, overseas dependency for the energy fuels and health related problems will only continue to increase.

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